Memo: Multi-intensive experiments

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1 Introduction

The purpose of so-called multi-intensive experiments was to assess the accuracy of determination of UT1 angle from hourly single baseline experiments which are observed daily under IVS Intensive programs. During a 24 hour session two independent sub-networks observe simultaneously. The first sub-network I of two stations, Kokee and Wettzell or Tsukub32 and Wettzell observe 20–23 consecutive 60 minutes long Intensive schedules. The second subnetwork M of 4–6 stations observe a usual 24 hour schedule in the style of R1/R4 sessions. Since the accuracy of UT1 from a multi-baseline 24 hour session is by the factor of 4–6 better than the accuracy of UT1 from a 60 minute long one-baseline experiment, the differences between the UT1 angle estimates determined from analysis of each Intensive 60 minute schedule and the UT1 derived at the same epoch from analysis of a multi-baseline 24 hour session can be considered as errors of intensive experiments. One 24 hour experiment provides sufficient amount of data in order to make a judgment about accuracy of UT1 determined from intensive experiment. Such a strategy allows quick and reliable assessment of accuracy of UT1 from Intensive and is suitable for testing different scheduling algorithms.

2 Experiments

There were four multi-intensive experiments in 2004–2006:

Table 1: List of multi-intensive VLBI experiments

min_01	$04JUN16XA	7	rd0404	1768	7	Ag Ft Gk Kk Ts Wf Wz
min_02	$04JUL07XA	8	rd0405	1633	8	Ag Ft Gk Kk Ny Ts Wf Wz
min_03	$04OCT27XA	8	rd0408	2577	8	Ag Ft Gk Kk Ny Ts Wf Wz
min_04	$06AUG23XA	7	rd0606	3352	7	Kk Mc Ny Sv Ts Ws Wf

2.1 Scheduling min_01

The 23 intensive hourly schedules at the baseline KOKEE/WETTZELL in the first experiment min_01 were prepared by D. Fisher by using the traditional approach. The purpose of this experiment was to provide an estimate of accuracy of UT1 derived from routine Intensive experiments at the baseline KOKEE/WETTZELL.

2.2 Scheduling min_02

The 20 intensive hourly schedules at the baseline TSUKUB32/WETTZELL in the second experiment min_02 were scheduled by D. Fisher using advanced scheduling strategy. The purpose of this experiment was to estimate the accuracy of UT1 derived from routine Intensive experiments at this baseline and to determine possible bias of UT1 claimed by some analyzed.

A brief description of min_02 scheduling procedure (letter of Dorothee Fisher of 2004.04.02_13:38:59+0200):

The intensive min_02 schedules are prepared using the manual mode of SKED. Each session is scheduled individually to be able to take changing geometry into account.

2.2.1 Scheduling parameters

The following catalogs were adapted for K4 Intensive recording: `antenna2Ecat, equip.cat, modes.cat, freq.cat, rx.cat, loif.cat, rec.cat, hdpos.cat, tracks.cat`.

- Minimum SNR is 25 for X-Band and 20 for S-Band.
- Minimum scan duration is 120 seconds.
- Sources of source.cat.geodetic with A and B graduation are used.
- Minimum elevation is 9°.
- Each schedule contains 20 scans.
- Only one tape should be needed.
- Each source should be involved twice at least.

2.2.2 Scheduling procedure:

1. Sky plots of available sources for each station are created with GMT. The output of SKED's `whatsup` command is used as input for that. Rising and setting sources for the session's time frame are displayed as well. These plots give a good impression of the sky coverage.

2. A first test schedule is created with special emphasis on using low declination sources and sources with low elevations as possible.

3. The SKED command solve creates an output file that can be transformed into a SOLVE superfile using the program sskedh.

4. SOLVE creates the normal equation matrix just from the geometry of the schedule using the following parameterization: clock offset and rate for Tsukuba, atmospheric path delay for both stations and UT1. The inverted normal equation matrix is used as a measure of the schedule's sensitivity for the unknowns and their correlations.

5. A second test schedule is being created while trying to improve weak points of the first test schedule. For example if the simulated sigma of the tropospheric delay has been unsatisfactory in the fist step it may help to introduce more scans with low elevations for the affected station. If estimation of UT1 has been quite bad, more scans with low declination are included. In addition bigger changes in the spatial directions from scan to scan may help to reduce the simulated correlations between the unknown parameters.

6. Quite a number of test schedules is created, then evaluated using the inverted normal equation matrix and compared to the others.

7. The schedule with the best and most uniform sensitivity for all unknown parameters is being selected. Thus the INT2 schedules are not only optimized for UT1 as the main objective but also for the tropospheric path delays.

2.3 1 Gbps min_03 experiment

The 21 intensive hourly schedules at the baseline KOKEE/WETTZELL in the third experiment min_03 were scheduled by D. Fisher using the same scheduling strategy as in min_03 observing session. The signal at station KOKEE and WETTZELL experiment was recorded using 2 bit sampling, 256 MHz recorded band, and the signal at other baselines was recorded at 1 bit sampling, 128 MHz recorded bandwidth. The purpose of this experiment was to demonstrate the advantages of wide-band recording mode suggested in late 80s.

2.4 Scheduling min_04 experiment

The 20 intensive hourly schedules at the baseline KOKEE/WETTZELL in the fourth experiment min_04 were scheduled by J. Gipson.

According to the session notes prepared by John Gipson, the first hourly schedule at the *I* sub-network was scheduled by Merri Sue Carter of USNO using the traditional intensive frequency sequence and observing strategy.

The remaining hourly schedule at the *I* sub-network were scheduled using the R1 observing frequency sequence. Merri Sue Carter and John Gipson alternated scheduling these. Merri Sue scheduled the ones starting on even hours: 20:00, 22:00, etc. She used the traditional intensive observing strategy.

John Gipson scheduled the intensives on the odd hours: 19:00, 21:00, etc, using two new features of sked: 1) Best-N, which selects the best sources for a session based on baseline geometry, and 2) Covariance optimization, which optimizes a schedule for a given quantity. The first of the second set of intensives starts at 19:04 to give the station operators time to switch disks etc.

The average (predicted) formal error for UT1 for the hourly intensive schedules prepared by Carter were 0.66 nrad[1]. For those scheduled by Gipson 0.54 nrad. This is an improvement of 20%.

3 Data analysis

Each of multi-intensive experiments consists of two sub-networks: one subnetwork of two stations, and another sub-network of 5–6 stations. The first phase of data analysis, fringe search, computation of group delays, computation of theoretical path delays and partial derivatives, resolving group delay ambiguities, outliers elimination and reweighing, was done for all the data in the experiment together. The second step of analysis, parameter estimation. was done separately for a single baseline sub-network and for the multi-baseline sub-subnetwork separately.

[1]Conversion factors to non-standard units: $1 \cdot 10^{-9}$rad ≈ 0.21mas $\approx 14\mu$sec

First, the preliminary so-called, pre_min solutions was made. It had a similar setup as the quarterly 2007a solutions. The differences was that the empirical expansion of the harmonic variations in the Earth rotation heo_20061210.heo with coefficients of sine and cosine amplitudes for three components of the perturbational Earth rotation vector at 742 harmonics derived from LSQ analysis of VLBI data from 1984.0 through 2006.9 was used. The 2007a solution used all the experiments, except multi-intensive.

The intermediate result of the global matrix inversion, so called combined global matrix was stored. Two iterations were done. At the second iteration the EOP files produced from the first solutions using the Kalman filter according the procedure developed by J. Gipson was used.

At the second step data for each hourly intensive part of the schedule at the sub-network I were extracted as 85 independent databases. These 85 intensive databases and 4 databases for multi-intensive experiments with data only at the sub-network M, in total 89 databases, were used in the second solution post_min. The post_min solutions used the input combined global matrix produced in the first step. Parameterization for first four databases with only sub-network M data was the same as parametrization for all other experiments in the pre_min solutions: source coordinates, site positions and velocities, harmonic variations in site positions at Sa, SSa, S_1, and S_2 frequencies were treated as global parameters. Pole coordinates and its rate of change, UT1, time derivative of UT1, nutation daily offsets were treated as local parameters.

Parameterization for hourly 85 databases for I sub-networks had different parameterization: only six parameters were estimated as local parameters: 1) clock offset, clock rate and clock acceleration at the reference station; 2) atmosphere path delay at each station considered as being constants over one hour interval; 3) UT1 angle. Other parameters were treated as global.

Since the combined global matrix from the pre_min solution was used as input, the post_min solution is equivalent to the single LSQ solution with all the data from August 1979 through November 2006, including four multi-intensive experiments.

Solution post_min was run 86 times. At the first run the reference epochs for 85 intensive databases were determine. These were the middle epochs among used observations. The following runs differed at one point: the reference epoch for UT1 in 4 multi-intensive experiments was changed each time to coincide with the reference epoch of one of intensive databases.

It should be noted that two mathematical models of the Earth orientation parameters are used: the a priori model and the estimation model. The a priori mathematical model for UT1 represents this parameter as a sum of two continuous functions of time: $\mathrm{UT1}_a(t) = \mathrm{UT1}_{ah}(t) + \mathrm{UT1}_{as}(t)$. The first constituent is the harmonic expansion: $\mathrm{UT1}_{ah}(t) = \sum_i^n u_i^c \cos\omega_i t + u_i^s \sin\omega_i t$. The second constituent is expansion over B-spline basis of the 3rd degree: $\mathrm{UT1}_{as}(t) = \sum_i^n s_i B_i^3(t)$, where $B_i^3(t)$ is the basis spline function. The coefficients of the interpolating cubic spline s_i are evaluated using 15 points of the a priori EOP series: 7 points preceding the experiment nominal start time and 8 points following the nominal start time. The estimation model of $\mathrm{UT1}_e(t)$ is $\mathrm{UT1}_e(t) = \mathrm{UT1}_e(t_0) * (t - t_0)$, where t_0 is the reference epoch. The total reported values are $UT1_t(t_0) = \mathrm{UT1}_e(t_0) + \mathrm{UT1}_{as}(t_0)$. The choice of the reference epoch t_0 allows us to map the total UT1 angle at desirable instance of time.

4 Results

Formal uncertainties of UT1 from sub-networks M were at a level of 0.2–0.4 nrad at experiments min_01, min_02, min_04. Formal uncertainties of UT1 from sub-networks I were at a level of 0.6–0.9 nrad. WE can consider UT1 from sub-networks M as a ground truth and interpret the differences in UT1 from these two sub-networks as a measure of accuracy of UT1 from hourly intensive schedules. Plots of the differences are presented in figures 1–3.

Table 2 summarizes the statistics. In the last two rows the experiment min_04 was split into two datasets: min_4a scheduled with the traditional strategy of Merri Sue Carter and min_4b scheduled with the advance strategy of John Gipson.

Table 2: Statistics of the differences in UT1 angles estimates from sub-networks I and sub-networks M. Units are nrad.

Experiment	#	bias	wrms	mean σ
min_01	24	-0.47	1.03	0.86
min_02	21	-0.92	0.85	0.94
min_03	22	0.29	2.18	2.06
min_04	21	0.57	0.89	0.65
min_4a	10	0.62	0.75	0.63
min_4b	11	0.52	1.09	0.66

Post figt residuals of the experiment min_03 recorded in 1 Gbps mode are anomalously high, 70 ps. Plots of residuals do not reveal an obvious pattern 4. The reason of poor fit was not determined. An attempt to demonstrate that wide-band VLBI technology provides an improvement in accuracy appeared unsuccessful.

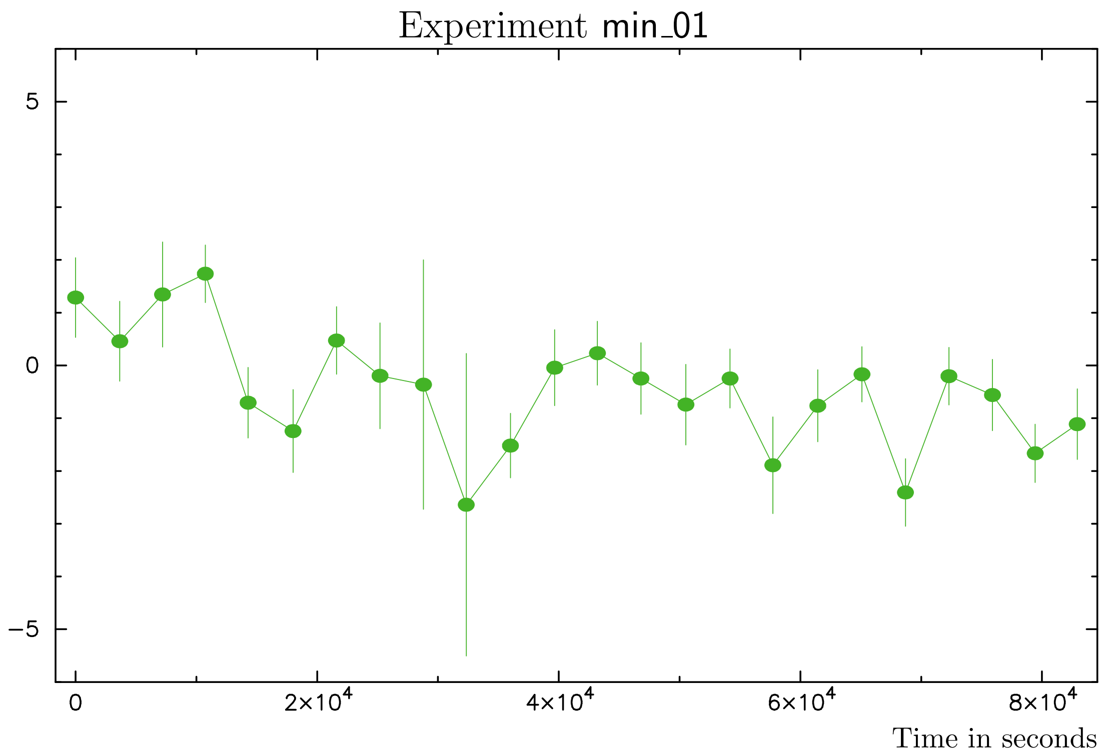
5 Conclusions

1. It was found that the the accuracy of UT1 from hourly intensive experiments is at level of 0.80–1.00 nrad.

2. It was no found offsets exceeding 1σ between UT1 from hourly experiments at baselines KOKEE/WETTZELL and TSKUBU32/WETTZELL.

3. Results of min_4a and min_4b contradicts claims that the formal uncertainties of simulations of min_4b are smaller than of min_4a. UT1 from min_4a were expected to be at the same level as min_01. We got that min_4a are 45% closer to UT1 from multi-baseline experiments. It was expected that an advanced strategy of scheduling in min_4b will produce better UT1 than in min_4a, but it turned out just opposite. I suspect an error in scheduling or schedule description was made.

Figure 1: Differences in UT1 at sub-network I and sub-network M in nrad.



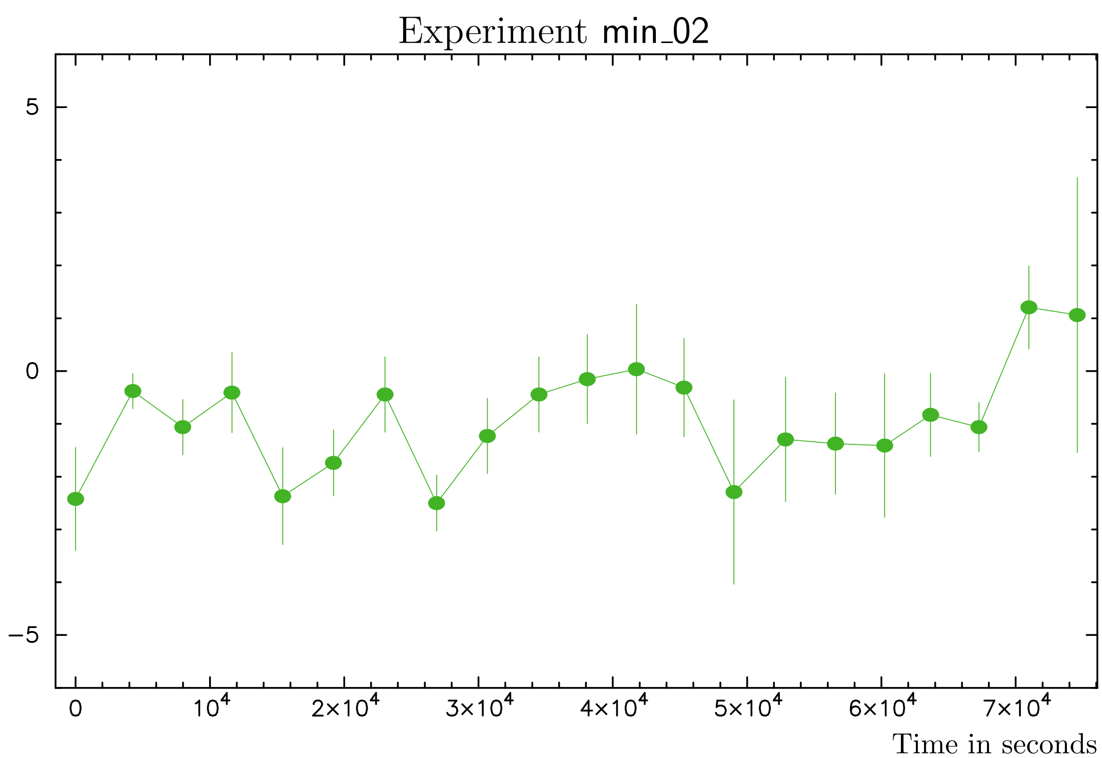
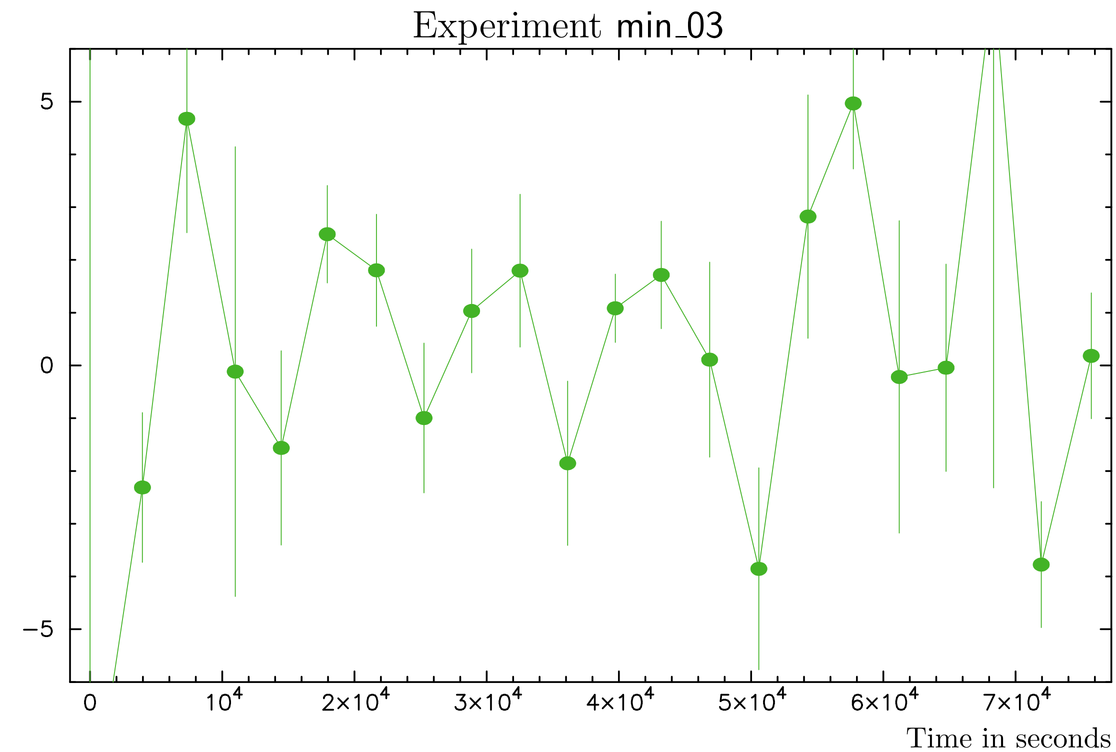


Figure 2: Differences in UT1 at sub-network I and sub-network M in nrad.



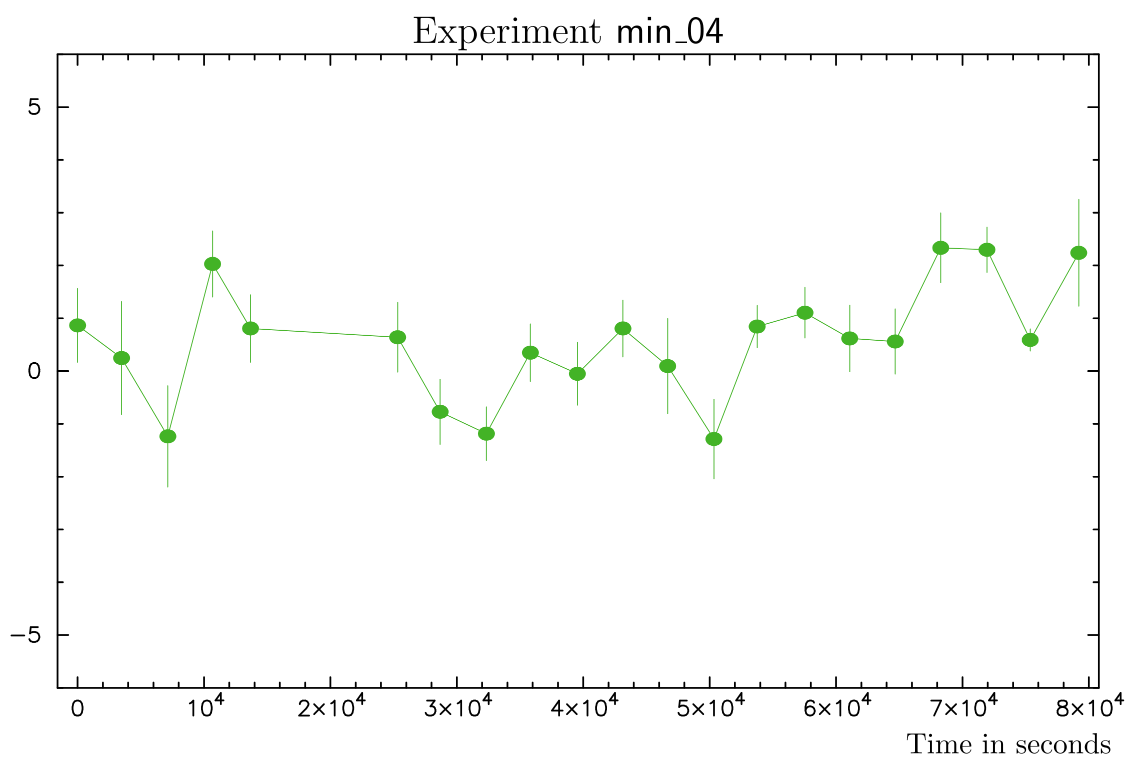
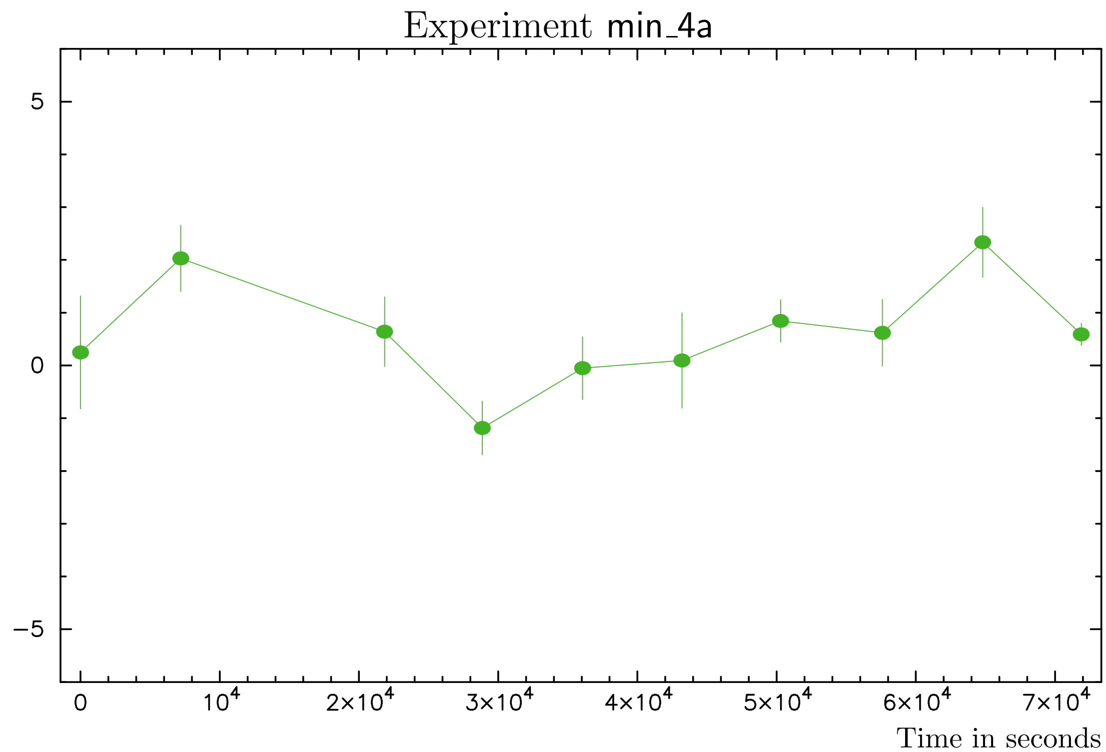


Figure 3: Differences in UT1 at sub-network I and sub-network M in nrad.



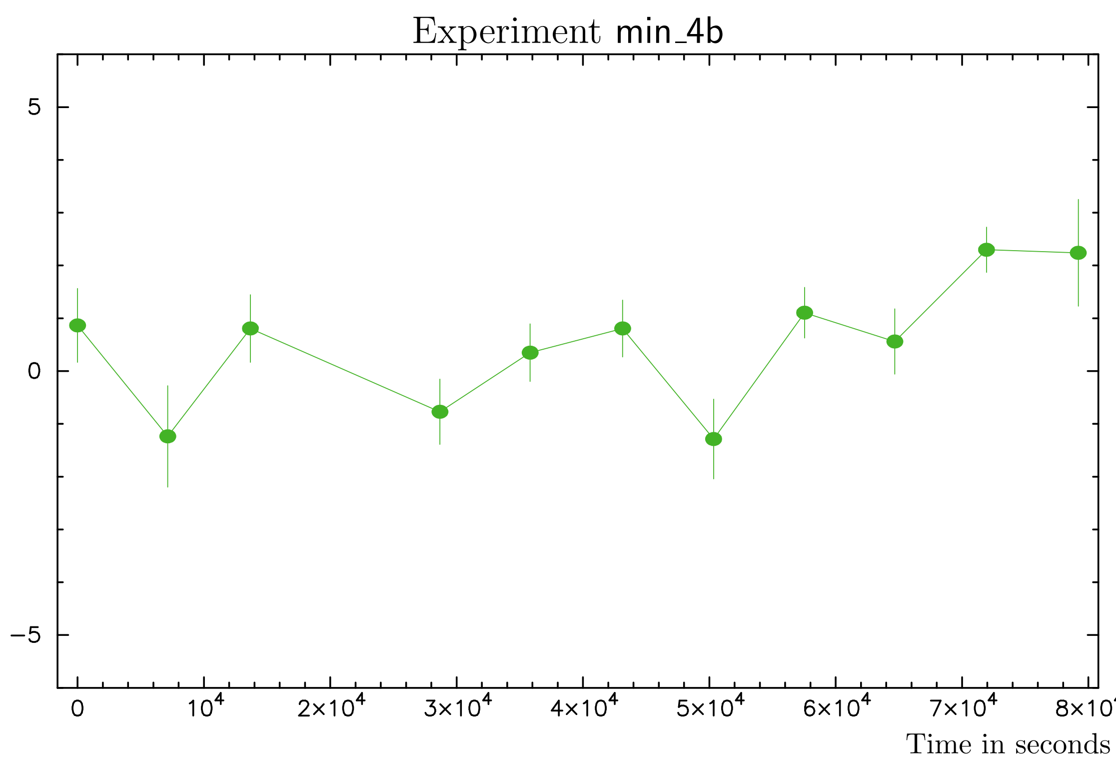


Figure 4: Postfit residuals from min_03 experiment.